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Boron requirement of chickpea (*Cicer arietinum* L.) cultivars to model based applied boron fertilizer on rainfed calcareous soils

Shahid Maqsood Gill*, **Ejaz Rafique, Sair Sarwar, Muhammad Mahmood-ul-Hassan**

Land Resources Research Institute, National Agricultural Research Centre, Islamabad, Pakistan

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Key words: Boron, Adsorption, Chickpea, *Cicer arietinum*, Calcareous soils, Diagnostic criteria

Abstract

Determining boron requirement through sorption isotherms is considered more accurate than conventional soil testing. Boron requirements of chickpea leaves and seeds were assessed from yield response curves based on model applied boron fertilizer under field conditions. Boron sorption isotherms were constructed by using Talagang (Fluventic Camborthid) and Balkassar (Typic Haplustalf) soil series at Murat and Tatral, Punjab Province, Pakistan, varying in their calcium carbonate and clay contents. Adsorption isotherms were constructed by equilibrating 3g soil with 30ml of 0.01M calcium chloride solution containing varying amounts of boron (0 to 1.6mgkg^{-1} soil). Langmuir and Freundlich adsorption models were used to assess the boron sorption parameters. Langmuir showed good fit of the sorption data ($r^2 = 0.99$). Six soil solution boron levels (0.005, 0.01, 0.02, 0.04, 0.08 and 0.12mg l^{-1}) were developed using sorption data and recommended N, P and K rates were applied as basal dose. Boron application significantly increased grain yield and boron uptake by all the chickpea cultivars over native soil boron. Soil solution boron requirement of chickpea cultivars for near-maximum relative seed yield at both soils was approximately the same (0.02mg l^{-1}). Internal boron requirement in leaves varied from 20-24mgkg^{-1} and in seed from 11-15mgkg^{-1}. The study indicates that exploitation of the genetic variation in chickpea can help to avoid B deficiency or reduce B fertilizer requirements without affecting crop productivity.

***Corresponding Author:** Shahid Maqsood Gill ✉ smgill@live.ca

Introduction

Boron (B) is essential for growth of new cells. It is not readily mobile in the plant and its deficiency causes the terminal bud to cease growth followed by death of young leaves (Dell and Huang 1997). Without adequate B, there is a reduction in number and retention of flowers, germination of pollen grains and growth of pollen tube resulting in the reduction of fruit development (Bell and Dell 2008; Dell *et al.,* 2002). The proportion of B in solid and liquid phases depends upon mineral composition, soil texture and solution pH (Goldberg 1997; Keren and Bingham 1985). Soil solution B concentration is mainly controlled by mineral and organic surfaces present in soil and adsorption processes. The most important B adsorption surfaces in soils are aluminum and iron oxides, clay minerals, calcium carbonate and organic matter (Goldberg 1997). Plants respond only to B activity in soil solution rather than that adsorbed by the soil surfaces (Keren *et al.,* 1985). As the range of soil solution B concentration triggering deficiency or toxicity in plants is relatively narrow, the knowledge of B adsorption behavior of the soil becomes imperative.

Sorption isotherms provide descriptions of experimental adsorption data without a theoretical basis. These isotherms assume that nutrient adsorption-desorption is a reversible process between solid and liquid phases and the relationship between the two phases can be described at equilibrium. These take into account intensity, quantity and capacity factors, which are important for predicting the amount of soil nutrient required for maximum plant growth. The amount of nutrients available in a soil are affected by soil properties that are not needed to be measured to determine plant nutrient requirements using sorption technique (Shafiq and Maqsood 2010, 2017). Various modeling approaches have been used to describe B adsorption reactions in soils. Classical empirical models used for sorption studies are Langmuir and Freundlich adsorption isotherm equations (Elrashidi and Connor 1982). Both equations contain two adjustable parameters and assume that adsorption occurs at constant solution pH.

Chickpea (*Cicer arietinum* L.) is an important grain legume in Asia and being a rich and cheap source of protein, it can help people improve the nutritional quality of their diets. It is grown and consumed in large quantities from South East Asia to India and in the Middle East and Mediterranean countries. Chickpea is of relatively minor importance on the world market but it is extremely important for local trade in numerous tropical and subtropical regions including Pakistan. Chickpea is generally considered to be less prone to B deficiency (Bell and Dell 2008). However, B deficiency may occur in chickpea because of particular B requirement to activate the early synthesis of ethylene, leading to the rapid worsening of seed quality. Further, B may cause yield loss up to 100% in chickpea (Ahlawat *et al.,* 2007). Hence, the area of B-deficient soils in regions where chickpea is planted could affect its productivity severely.

Information regarding the sensitivity of chickpea to B deficiency, use of B sorption isotherm for determining fertilizer B requirement and critical B concentrations in plant parts of the crop (especially seed) are reported for specific genotypes and zones. Hence, plant critical levels published in the literature may not be apposite for various crop genotypes grown in different agro-ecological zones.

Considering the likely importance of B deficiency of chickpea in Pakistan, the objectives of the present study were to: (1) use B sorption isotherms for determining fertilizer B requirement in two soils, (2) determine critical B concentrations in plant tissues, and (3) evaluate genotypic variation in chickpea.

Materials and methods

Experimental sites

Field experiment was carried out under rainfed conditions on two major soil series (Talagang and Balkassar) of the Pothwar plateau in Punjab, Pakistan. The Talagang soil series (coarse loamy mixed, hyperthermic Fluventic Camborthid) was located at Murat (latitude 32° 55ʹ N; longitude 72° 25ʹ E) and Balkassar soil series (coarse silty mixed, hyperthermic Typic Haplustalf) was located at Tatral (latitude 32° 78' N; longitude 72° 70' E) in district Chakwal. The soils have been developed with transported materials consisting of loess and lie under semiarid and sub-humid subtropical continental climate. Both the experimental sites were low in organic matter, alkaline, calcareous and deficient in essential plant nutrients (Table 1).

Table 1. Selected initial soil physical and chemical characteristics of two experimental sites.

Characteristics	Murat soil	Tatral soil
Soil series	Talagang	Balkassar
Soil family	Coarse loamy mixed, hyperthermic Fluventic Camborthid	Coarse silty mixed, hyperthermic Typic Haplustalf
Clay (%)	15	26
Silt (%)	8	32
Texture	Sandy loam	Loam
$pH_{1:1}$	7.9	8.2
$EC_{1:1}$ (dSm^{-1})	0.40	0.47
Organic matter (%)	0.50	0.29
$CaCO_3$ (%)	1.9	2.2
AB-DTPA extractable* ($mgkg^{-1}$)		
NO_3-N	2.5	4.5
P	1.7	2.4
K	80	110
Zn	0.30	0.45
HCl extractable** ($mgkg^{-1}$)		
B	0.05	0.12

*Soltanpour and Workman, 1979

**Ponnamperuma *et al.,* 1981

Laboratory boron sorption experiment

Boron sorption isotherms were constructed by equilibrating 3.0g of soil from each site with 30ml 0.01M calcium chloride solution containing varying amounts of B (0 to 1.6mgkg^{-1} soil) as boric acid for 24 hours at 25±1°C in three replicated experiment. After centrifugation, the B content of the supernatant was determined using Azomethine-H method for color development and measuring absorbance at 420nm on spectrophotometer (Keren 1996). The difference between the amounts of B in equilibrating solution before and after equilibrium was taken as the amount of B sorbed. Sorption data was fitted to the linear forms of the Langmuir and Freundlich models to calculate the sorption parameters.

Langmuir model

The Langmuir equation may be written as:

$$\frac{x}{m} = \frac{KCb}{1 + KC}$$

where $\frac{x}{m}$ = amount of B absorbed per unit of soil (mgkg^{-1})

C = equilibrium B concentration in soil solution (mg l^{-1})

K = constant related to binding strength of B to the soil

b = maximum adsorption (mgkg^{-1})

Freundlich model

The empirically derived Freundlich equation is:

$$x = aC^b$$

where x = amount of B absorbed per unit of soil (mgkg^{-1})

C = equilibrium B concentration in soil solution (mg l^{-1})

a and b = sorption constants which represent the intercept and slope of the sorption isotherms, respectively.

Field experiment

Six soil solution B levels (0.005, 0.01, 0.02, 0.04, 0.08, and 0.15mg l^{-1}), in addition to the original soil solution B, were developed by applying the corresponding amount of B computed based on the sorption study (Table 2). Three chickpea cultivars (CM 2008, Parbat and Dashat) were tested in the present study. The treatments were arranged in a Split-Plot Design with three replications. Chickpea cultivars were in the main plots and B application levels were in the sub-plots. Recommended rates of nitrogen (25kg ha^{-1}) as urea, phosphorus (40kg ha^{-1}) as single super phosphate, and zinc (5kg ha^{-1}) as zinc sulfate were applied as basal dose. All nutrients were applied during final seed bed preparation. The plot size was 4m × 2.1m and seeds were sown (75kg ha^{-1}) during the first week of October with row to row and plant to plant distance of 30 and 10cm, respectively. Weeding and other cultural practices were performed as and when required. Composite diagnostic plant tissue (recently matured leaves at flower initiation stage) were collected (Jones *et al.,* 1991). Harvesting was done in April and data regarding grain and straw yield was recorded.

Table 2. Langmuir model based soil solution B levels and their equivalent fertilizer B rates applied to three chickpea cultivars at two experimental sites.

Adjusted soil solution B levels (mg L^{-1})	B rates (kg ha^{-1})	
	Murat soil	Tatral soil
Native	0.001	0.0015
0.005	0.257	0.309
0.010	0.495	0.590
0.020	0.923	1.077
0.040	1.609	1.796
0.080	2.539	2.613
0.120	3.330	3.347

Boron analysis

After necessary processing (washing, drying, grinding and sieving), plant tissues (leaf and seed) were taken in porcelain crucibles and dry-ashed in muffle furnace at 550°C overnight, the ash was taken up in 0.36N sulfuric acid (Gaines and Mitchell 1979) and was filtered. The concentration of B in the aliquots was determined by colorimetry using azomethine-H method (Keren 1996). Internal B requirements, the concentration of B in specific tissue which was sufficient for 95% of maximum yield, were determined by plotting relative pods yield versus B concentration using a boundary line technique (Webb 1972).

Analysis of variance of the measured parameters was performed using computer program Statistix version 8.5 and the means were compared using Tukey's test at 5% probability level (α = 0.05).

Results and discussion

Soil solution B concentration at equilibrium with adsorbed phase serves as an index of B availability using adsorption isotherm technique (Tsadilas *et al.*, 2005). Boron sorption isotherms for both the soils (Fig. 1) and their linearized forms (Fig. 2) depicted an increase in B sorption with its increasing concentration in the equilibrium solution, within the range studied. The differences between the soils in the amount of B sorbed at the same level of B added indicate variation in their B sorption capacity resulting in different rates of fertilizer B for the corresponding equilibrium concentration (Table 2). Similar procedure has been adopted to find out B fertilizer rates to adjust desired soil solution B level to get maximum yield (Shafiq and Maqsood 2010, 2017).

The rate of increase in B sorption with its increasing concentration in equilibrium solution was higher initially for both soils (Fig. 1) up to 0.03mg l^{-1} but it reduced drastically at higher B concentrations in equilibrium solution. Tatral soil had significantly higher B sorption than Murat soil for all corresponding concentrations of B in equilibrium solution. This may be attributed to higher clay content in Tatral soil (Table 1). Arora and Chahal (2007), Padbhushan and Kumar (2017), Krishnasamy *et al.* (2005) and Tamuli *et al.* (2017) also reported a very strong positive correlation between soil clay content and B sorption.

The adsorption isotherms for both soils (Fig. 1) could be divided into two parts. The first one is a high adsorption affinity part at low equilibrium concentration, where sorption increases almost linearly with increasing equilibrium concentration. The second one is a plateau where rate of adsorption reduces with an increase in solution concentration, moving towards an adsorption maximum. Goldberg (1997) explained B adsorption by clay minerals as a two-step process in which B adsorbs initially onto the clay particle edges and subsequently incorporates structurally into tetrahedral sites replacing structural silicon and aluminum. Similar findings were also observed by other researchers (Couch and Grim 1968; Tamuli 2017).

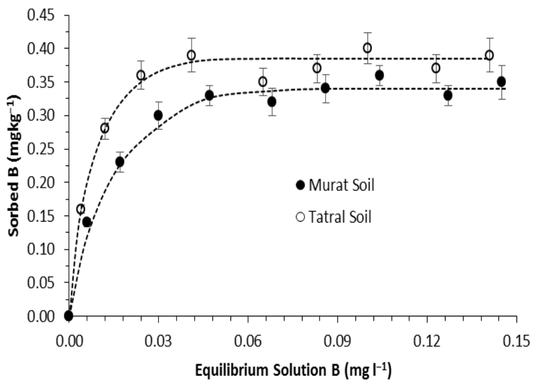

Fig. 1. Boron sorption fitted to Langmuir isotherm (dashed lines) for two soils from the experimental sites.

The sorption data for both soils conformed to Langmuir isotherm which had significantly higher regression coefficient (r^2) values than Freundlich isotherm for both soils. Langmuir isotherm had r^2 values of 0.994 and 0.996 while Freundlich isotherm had 0.985 and 0.974 for Murat and Tatral soils, respectively. Therefore, B sorption parameters calculated by Freundlich isotherm are not discussed and Langmuir sorption isotherms were used to develop soil solution B levels by adding equivalent B rates (Table 2) in the field study. Linearized forms of Langmuir isotherms (Fig. 2) were used to derive sorption parameters (Table 3). Maximum sorption (b) and binding strength (K) as determined from reciprocals of slope and intercept of the regression lines of Langmuir equation, respectively, were greater in Tatral soil compared with the Murat soil (Table 3). This difference appears to be related to the clay content as previously reported (Communar and Keren 2005).

Table 3. Langmuir boron sorption isotherm parameters of soils from the experimental sites.

Treatments	Murat Soil	Tatral Soil
Maximum Sorption (b) (mgkg^{-1})	0.357	0.394
Binding strength (k) (Lkg^{-1})	165	219
Regression coefficients (r^2)	0.994	0.996

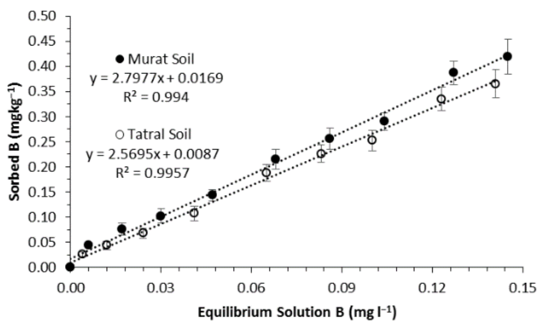

Fig. 2. Boron sorption fitted to linearized Langmuir isotherm (dotted lines) for two soils from the experimental sites.

Boron requirement of chickpea

The nutrient requirement of crops can be expressed as the "internal nutrient requirement" or the "critical nutrient concentration in plant tissue", and the "external nutrient requirement". The term "internal nutrient requirement" refers to the concentration of a nutrient in a particular plant part associated with 95% of the highest yield attained when that nutrient (the primary limiting nutrient) is just adequately supplied for nutritional purposes (Rashid and Fox 1992). Chickpea cultivars showed significantly varying responses with an increase in B levels at both sites (Table 4). Magnitude of crop response to B was better in coarse loamy Talagang soil at Murat site than that of coarse silty Balkassar soil at Tatral site. Maximum increase in grain yield with B application over native level of soil B was 18% at Murat site and 15% at Tatral site for Dashat cultivar, while this increase in Parbat andcm-2008 cultivars was 13% and 11% at Murat site and 12% and 9% at Tatral site, respectively (Table 5). Grain yields of all cultivars were lower at Murat site as compared to Tatral site. This can be attributed to relatively poor climatic conditions (drought and temperature etc.) that occurred at this site. However, the magnitude of increase in grain yield was higher at Murat site as compared to Tatral site. It may be attributed to the lower initial soil nutrient status and the differences in native organic matter status in the two soils, which was 72% higher at Murat site than at Tatral site. The role of B in increasing yields in calcareous soils is well known (Ceyhan *et al.,* 2007; Rafique *et al.,* 2014; Rashid 2005). In a field study at soil deficient in available B (0.19mgkg^{-1}), the application of B fertilizer at the rate of 1.0kg ha^{-1} as boric acid increased 5-23% yield of chickpea cultivars in Turkey (Ceyhan *et al.,* 2007). However, the increase in chickpea yield was substantially higher (49%) with the same rate of B applied as borax to alkaline calcareous soil deficient in available B (0.17mgkg^{-1}) in north Bihar, India (Kumar *et al.,* 2006).

Being a legume crop, chickpea requires B for normal development of reproductive tissues and its deficiency results in low grain set or poor seed quality (Dell *et al.,* 2002). Also, B deficiency may trigger the early synthesis of ethylene leading to rapid deterioration of seed quality. Boron is involved in transport of sugars across cell membranes and in synthesis of cell wall material (Gupta and MacLeod 2006).

Some studies suggest that selection of cultivars with an increased sugar alcohol content can result in increased B uptake by translocating it as a complex sugar alcohol in phloem (Bellaloui *et al.,* 1999). It promotes elongation of epicotyls and hypocotyls and increased height of seedlings (Yang and Zhang 1998). Boron deficiency can inhibit the growth of seedlings (Wang *et al.,* 1999).

Boron plays an important role in maintaining the integrity of plasma membranes of leaf cells and in alleviating the damage of membrane caused by low temperatures (Wang *et al.,* 1999). Deficiency of B results in a marked decrease in the number of flowers and the flowers of B-deficient chickpea plants lack pigmentation and fail to fruit, causing reductions in pod and grain yield (Strivastava *et al.,* 1997).

Table 4. Grain yield of chickpea cultivars (kg ha^{-1}) as affected by adjusted soil solution B levels at the experimental sites.

Adjusted soil soln. B (mg L^{-1})	Murat soil				Tatral soil			
	CM 2008	Parbat	Dashat	Mean	CM 2008	Parbat	Dashat	Mean
0	1848	1695	1565	1703 C	2017	1874	1742	1878 B
0.005	1920	1793	1700	1804 BC	2080	1970	1880	1977 AB
0.010	1950	1817	1730	1832 AB	2119	2003	1933	2019 A
0.020	2040	1913	1842	1932 A	2174	2068	2010	2084 A
0.040	2047	1920	1810	1925 A	2188	2092	1975	2085 A
0.080	2005	1863	1807	1892 AB	2137	2025	1940	2034 A
0.120	1975	1826	1762	1854 AB	2093	1997	1885	1992 AB
Mean	1969 A	1832 B	1745 C		2115 A	2004 B	1909 C	

Means sharing same letters and those with no letters within main or interactive effects are not statistically different at α=0.05.

Table 5. Effect of B application on grain yield of chickpea and B efficiency of cultivars grown on B-deficient soils.

Cultivar	Dry pod yield (kg ha^{-1})		% increase over control	B efficiency* (%)
	0kg B ha^{-1}	Maximum with B applied		
		Murat soil		
CM 2008	1848	2047	11	90
Parbat	1695	1920	13	88
Dashat	1565	1842	18	85
Mean	1702	1936	14	88
		Tatral soil		
CM 2008	2017	2188	9	92
Parbat	1874	2092	12	89
Dashat	1742	2010	15	87
Mean	1878	2097	12	89

*Boron efficiency was calculated as the relative ratio of grain yield at control to maximum pod yield at +B.

Plant response to low B in the soil varies widely among species and genotypes within a species. Genotypes efficient in B are able to grow well in soils in which other genotypes are adversely affected by B deficiency (Rerkasem and Jamjod 1997). Based on the reduction in grain yield, efficiency (ratio of grain yield produced under control to applied B) of chickpea cultivarcm-2008 (Table 5) was the highest (90 and 92%) whereas cultivar Dashat was the lowest B efficient (85 and 87%). The efficiency of chickpea cultivars grown at both sites, under given conditions, declined in the order ofcm-2008 > Parbat > Dashat. Generally, in B deficient soil (control), cultivars having higher B-efficiency take up more B and use for additional dry matter production. Thus, this additional B is diluted to similar concentrations as in the inefficient cultivars, and do not accumulate per unit yield weight. It seems that B-efficient cultivars have more physiologically active B than inefficient cultivars. Significant differences have been reported among peanut and mung-bean cultivars in their sensitivity to B deficiency (Rafique *et al.,* 2014, 2016). Rerkasem *et al.* (1993), while screening several wheat cultivars, observed relative grain yields with low levels of B application ranging from 11% (for the most B-inefficient cultivar) to 97% (for the most B-efficient cultivar). It indicates that at low levels of external B, plant responses varied from low grain set in case of inefficient genotypes to high grain set in efficient genotypes.

Internal B requirement and total uptake

Higher B concentration in diagnostic plant parts of chickpea (leaves and seed) was observed as a consequence of B application and all the B levels were significantly superior to native soil B at both sites (Table 6). However, the extent of variation differed amongst the cultivars. Diagnostic plant parts behaved differently to B application as increase in B concentration in leaves was greater than that in seeds because B translocates to leaves through transpiration streams and deposits in the leaf margins on transpiration (Jones *et al.,* 1991). The range of B concentration in leaves of different cultivars was 15-32mgkg^{-1} incm-2008, 17-36mgkg^{-1} in Parbat and 18-37mgkg^{-1} in Dashat. Similarly, the range of B concentration in seeds of different cultivars was 7-20mgkg^{-1} incm-2008, 9-24mgkg^{-1} in Parbat and 10-27mgkg^{-1} in Dashat. Average B concentration was higher at Tatral site than at Murat site. Consequently, magnitude of increase in crop B concentration with B application was higher at Murat site, compared with Tatral site. Published data adequately reveals that, in general, magnitude of plant responses are correlated with soil extractable level of nutrients (James *et al.,* 1995; Lloveras *et al.,* 2004).

Estimated critical levels of B in chickpea cultivar tissues were 20mgkg^{-1} in leaves and 11mgkg^{-1} in seed ofcm-2008, 23mgkg^{-1} in leaves and 13mgkg^{-1} in seed of Parbat and 24mgkg^{-1} in leaves and 15mgkg^{-1} in seed of Dashat cultivars (Fig. 3). At both sites, total B uptake by all the chickpea cultivars increased with increasing B levels (Table 6) as evident by an increase in the yield and B concentration over native B level. The lowest total B uptake was observed in control and the highest with soil solution B level of 1.6mg B l^{-1}. Total B uptake by crop exhibited significant variation affected by cultivars. The range of B uptake by different cultivars of chickpea was 41-98mgkg^{-1} in cm-2008, 46-107mgkg^{-1} in Parbat and 47-112mgkg^{-1} in Dashat cultivars.

Table 6. Boron concentration in different parts and B uptake by chickpea cultivars as affected by adjusted soil solution B levels.

Adjusted soil soln. B (mg L^{-1})	Murat soil				Tatral soil			
	CM 2008	Parbat	Dashat	Mean	CM 2008	Parbat	Dashat	Mean
	-------------------------B concentration in leaves (mgkg^{-1})-------------------------							
0	15.7	17.7	19.3	17.6 F	18.3	21.3	21.3	20.3 F
0.005	17.7	19.7	20.7	19.3 E	20.0	23.0	23.0	22.0 E
0.010	18.7	20.7	21.7	20.3 E	20.7	24.0	25.0	23.2 E
0.020	21.3	22.7	24.0	22.7 D	23.0	26.3	28.3	25.9 D
0.040	24.0	27.3	28.0	26.4 C	25.7	29.3	30.0	28.3 C
0.080	26.3	29.7	31.0	29.0 B	28.3	32.0	32.7	31.0 B
0.120	29.3	34.3	33.7	32.4 A	31.3	35.3	36.0	34.2 A
Mean	21.9 C	24.6 B	25.5 A		23.9 B	27.3 A	28.0 A	
	-------------------------B concentration in grain (mgkg^{-1})-------------------------							
0	8.3 n	10.3 lm	10.7 kl	9.8 F	10.3 l	10.3 l	13.3 hij	11.3 F
0.005	8.7 mn	11.0 kl	12.0 jkl	10.6 F	11.0 kl	12.3 jkl	15.0 ghi	12.8 E
0.010	10.3 lm	11.7 jkl	13.3 ij	11.8 E	12.3 jkl	12.7 jk	16.3 fg	13.8 E
0.020	12.3 jk	14.3 hi	15.7 fgh	14.1 D	13.0 ijk	15.3 gh	18.0 ef	15.4 D
0.040	15.3 gh	16.7 efg	18.3 de	16.8 C	15.7 g	17.0 fg	20.7 c	17.8 C

Adjusted soil soln. B (mg L⁻¹)	Murat soil				Tatral soil			
	CM 2008	Parbat	Dashat	Mean	CM 2008	Parbat	Dashat	Mean
0.080	17.3 ef	19.3 cd	20.7 bc	19.1 B	18.3 def	20.3 cd	23.7 b	20.8 B
0.120	19.3 cd	22.3 b	25.3 a	22.3 A	20.0 cde	24.0 b	26.7 a	23.6 A
Mean	13.1 C	15.1 B	16.6 A		14.4 C	16.0 B	19.1 A	
	------------------------------Total B uptake (g ha⁻¹)--------------------------------							
0	41	46	47	44 G	56	55	61	57 F
0.005	44	50	55	50 F	61	63	71	65 E
0.010	50	54	60	55 E	67	67	77	70 E
0.020	61	66	71	66 D	75	78	89	81 D
0.040	72	78	78	76 C	85	86	102	91 C
0.080	77	83	87	82 B	93	95	108	99 B
0.120	89	94	101	94 A	98	107	112	106 A
Mean	62 C	67 B	71 A		76 C	79 B	89 A	

Means sharing same letters and those with no letters within main (uppercase) or interactive (lowercase) effects are not statistically different at α=0.05.

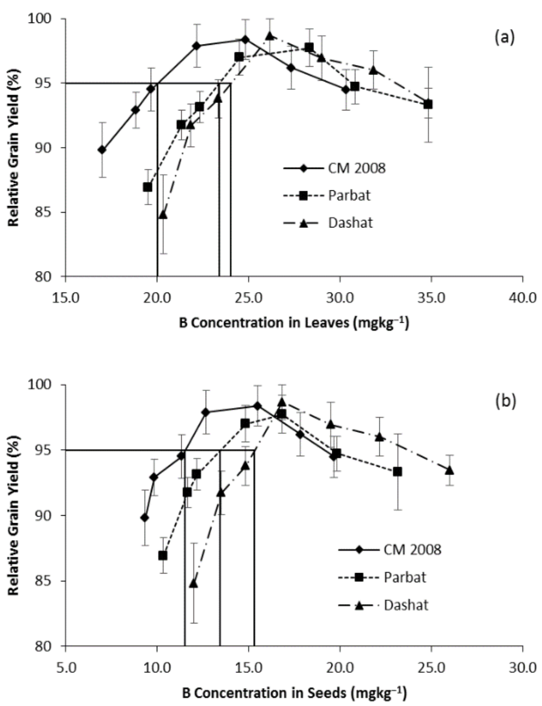

Fig. 3. Relationship between B concentration in leaves (a) and seeds (b) with relative grain yield of three chickpea cultivars (average of two sites).

Critical levels of B in diagnostic plant parts of chickpea (leaves and seed) are not satisfactorily reflected in literature. For example, Reuter *et al.* (1997) listed 22mg Bkg⁻¹ as critical deficiency in youngest mature leaf of chickpea. Rashid and Ryan (2008) observed that chickpea leaves containing 49mg Bkg⁻¹ were B-deficient. Noppakoonwong *et al.* (1997) recommended 12-18mg Bkg⁻¹ dry weight in the fully expanded leaf blade for diagnosis of B deficiency in black gram. This shows that critical level of B in diagnostic plant parts of chickpea varies considerably. The variation in critical level of nutrients can occur presumably due to differences in crop genotypes and plant age (Jones *et al.,* 1991). There are also many reports that critical concentrations for diagnosing nutrient deficiencies vary as a result of interactions with other nutrients and climatic conditions (Munson and Nelson 1990). Plant species also differ markedly in their abilities to absorb B from the soil under given conditions (Gupta 1979). Even species of the same genus and cultivars of the same species appear to differ in their internal nutrient requirements (Tang and Robson 1993). Most of the variations in critical concentrations probably arise from differences among species in the age and vegetative composition of the samples analyzed and in nutrient supply during the calibration experiments. The differences in B demand among species are related to differences in their cell wall composition, with species containing high pectin levels in their cell walls having higher internal B concentrations (Hu *et al.,* 1996). Moreover, species may also differ in their capacity for silicon uptake, which is usually inversely related to B, as well as calcium requirements (Loomis and Durst 1992) and all three elements are located mainly in cell wall. Seed has also been used to diagnose seed quality for a number of nutrients and crops. For example, critical concentrations have been defined for seed deficiencies of calcium in peanuts (Cox *et al.,* 1976), zinc in corn (Rashid and Fox 1992) and pea (Rafique *et al.,* 2015).

Conclusions

Langmuir and Freundlich adsorption models were used to assess the boron sorption parameters in this study. Langmuir showed good fit of the sorption data (r^2 = 0.99) indicating that B fertilizer applied on the basis of soil solution concentration can help to predict the fertilizer B requirement for various crops and soils. Boron application significantly increased grain yield and boron uptake by all the chickpea cultivars over native soil boron. Soil solution boron requirement of chickpea cultivars for near-maximum relative seed yield at both soils was approximately the same (0.02mg l^{-1}). Internal boron requirement in leaves varied from 19-24mgkg^{-1} and in seed from 10-15mgkg^{-1}. Cultivar Dashat grown in B-deficient soils is likely to suffer much higher yield loss than other cultivars. The present study also indicates that exploitation of the genetic variation in chickpea can help to avoid B deficiency/or reduce B fertilizer requirements without affecting crop productivity.

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